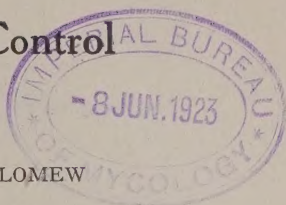


Apple Rust and Its Control in Wisconsin

L. R. JONES AND E. T. BARTHOLOMEW



KEEP THEM APART

If the Wealthy apple and the red cedar stand within sight of each other the rust will attack them. It can pass the winter only on the cedar.

AGRICULTURAL EXPERIMENT STATION
OF THE UNIVERSITY OF WISCONSIN

MADISON, WISCONSIN

DIGEST

Apple rust is on the increase in Wisconsin wherever the red cedar and apple are found growing in the same neighborhood. The red cedar is widely scattered in southern and western Wisconsin, which means in all of the important apple growing sections except Door County and Bayfield peninsulas. Pages 3 and 14-16

Apple rust appears as yellowish spots on both sides of the apple leaves in early summer and in severe cases causes premature dropping of the leaves. Severe outbreaks for two or three years will seriously injure or even kill the trees of susceptible varieties. The disease sometimes attacks the young fruit and also the twigs. Pages 3 and 12-13

The rust fungus passes from the apple leaves to the red cedar and causes gall-like swellings to appear on the cedar twigs the first season after infection. During the spring rains in the second season these galls send out jelly-like tongues bearing millions of spores. These spores in turn are carried to the apple leaves by the wind and cause rust spots to appear. This fungus can only continue to exist where it can live on the red cedar through the winter. Pages 8-14

Spraying the apple does not fully control the disease. This is advised only when cedars cannot be removed or resistant varieties planted. Bordeaux mixture has given most satisfaction. Two or three applications may be necessary to keep the leaves covered during the susceptible period of May and June. Spraying the cedar is without value. Pages 16-23

Removal of the red cedars is always advised because the rust fungus cannot live over winter except on these trees. Pages 23-25

Apple varieties show a difference in disease resistance. Some highly susceptible varieties are, Wealthy, Jonathan, and Dudley; resistant varieties, Fameuse, Northwestern Greening, and McIntosh. Pages 25-28

This photograph of an apple tree used in the front page illustration is reproduced by courtesy of the Wisconsin State Horticultural Society.

Apple Rust and Its Control in Wisconsin

L. R. JONES AND E. T. BARTHOLOMEW

As apple culture in Wisconsin, in both commercial and home orchards, rapidly increases, there naturally follows an increase in loss from diseases.

Heretofore our orchardists have been most concerned with the appearance of the two parasitic diseases known as scab and fire blight¹ which occur in practically all Wisconsin orchards and may cause much loss. Recently in certain sections even more concern has resulted from the advent of the rust², an entirely different parasitic disease which should not be confused with these others.

The rust first begins to show on the apple leaves as small pale yellow spots soon after the leaves develop in early summer. These spots enlarge until in later summer they may be from a quarter to half an inch in diameter and, if abundant, run together so as to cover much of the leaf surface (Figure 1). The color deepens at the same time to a bright orange yellow, often made more conspicuous by the development of reddish borders. In July and August the spots thicken or puff out on the lower leaf surface and become studded over with minute tubular projections of which the outer ends split open, roll back, and discharge from the center an abundant crop of spores. The fruit may be similarly attacked as shown in Figure 2. The tender twigs too are sometimes attacked although we have not observed this on the cultivated apple in Wisconsin. The rusted tissues are, of course, killed. We have not

¹ Scab is caused by the parasitic fungus *Venturia inaequalis* (Cke.) Wint. and fire blight by the parasitic bacterium *Bacillus amylovorus* (Burr.) Trev.

² There are two species of the apple rust fungi which occur in Wisconsin. *Gymnosporangium globosum* Farl. which is a common cause of apple rust in New England, occurs but sparingly here and causes little commercial loss. *Gymnosporangium juniperi-virginianae* (Schw.) Arth. (*G. macropus*, Lk.) is, however, widespread and injurious. All the observations recorded in this bulletin refer to this latter species; they would, however, apply almost equally well to the former.

observed that the attacks on the fruit of the cultivated apple are common enough to be commercially serious, although where they do occur the rusted fruits are ruined. The great damage comes from the early death of the leaf



FIG. 1.—RUSTED APPLE LEAVES

Upper surface of leaf shown at left and lower surface at right. The rust spots are bright yellow, sometimes bordered by reddish margins, and so quite conspicuous. For further details see later descriptions and Figure 2. (Photo by Giddings and Berg.)

tissues and where the attack is bad the leaves begin to fall in midsummer. This so greatly weakens the tree that growth and fruit development are checked and in the case of certain varieties the gradual death of the tree follows.

The apple rust fungus differs from most other such parasites, such as apple scab, in that it cannot live over winter on the apples or apple trees and the spores produced on

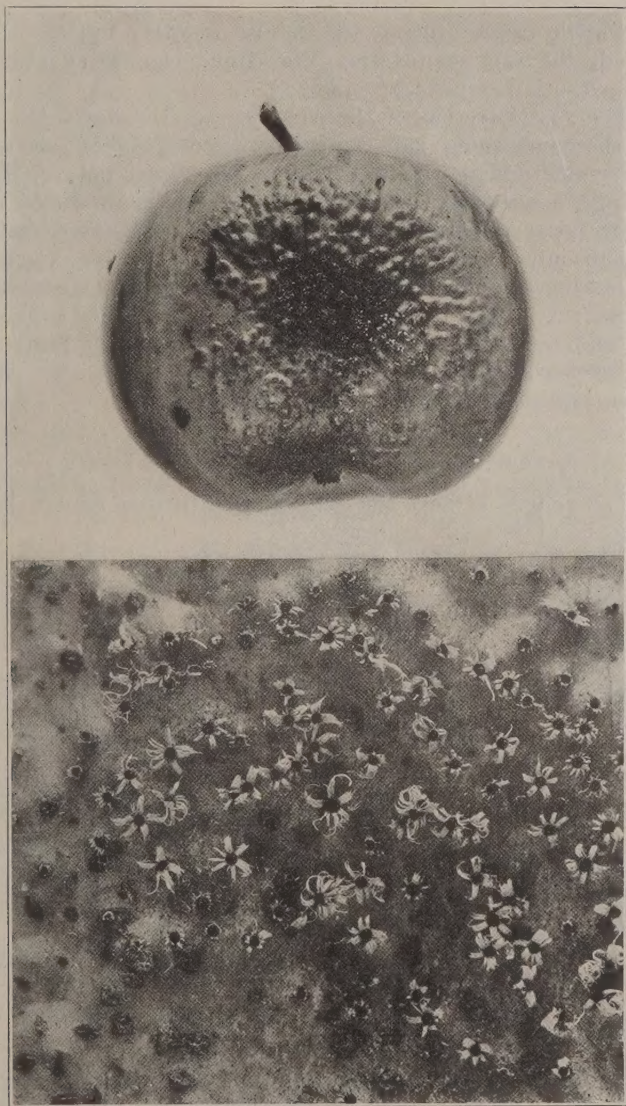


FIG. 2.—RUST ON AN APPLE

The fruit is less commonly attacked than is the leaf. The upper figure shows the various stages of development of the fungous pustules natural size. The lower figure is a photograph of the central part of this area enlarged showing the open spore cups with the spore masses in the interior of each. For further details compare with Figure 7.

the apple cannot spread the disease to other apples. Instead, the rust spores from the apple can develop only upon the red cedar (red juniper³).

The rust infection of the cedar causes the development of the conspicuous galls known as "cedar apples" on the cedar tree and it can live through the winter only on the cedar. Another abundant crop of spores is produced on these cedar apples in the spring which, curiously again, cannot infect the cedar, but establish themselves on the young leaves or fruit of the apple and so in turn cause the apple rust. The details as to the development will be stated later. These facts serve, however, to show that the occurrence and spread of the rust is dependent upon the close association of the red cedar and the apple.

OCCURRENCE OF APPLE RUST IN WISCONSIN

The fungus attacks not only the cultivated apples, but also the native wild crab apples⁴.

Since both the red cedars and the wild crab apples were scattered through the original forests of southern Wisconsin, the rust fungus doubtless occurred with equally wide distribution before the settlement of the state. It does not seem to have attacked the early apple orchards to any serious degree, however, so far as available records show. This may be attributed to one or more of the following causes.

(1) Relative scarcity of the native hosts. Both the red cedar and the wild crab are trees which multiply rapidly as "weed trees" in partially cleared wood lots, neglected pastures, and fence rows. Doubtless they are much more numerous now in such places and in certain types of open woodland than they were in the original forests.

(2) Relative scarcity of the parasite on its native hosts. Undoubtedly the conditions which have favored these increases of host plants in close proximity have favored the increase of the fungus.

³ This is the common "red cedar" native to Wisconsin (*Juniperis virginiana* Linn.). As will be explained in detail later, this tree occurs commonly, especially in rocky woodlands and bordering lakes and streams, in southern and western Wisconsin. It should not be confused with the still more common and widely distributed "white cedar" or arbor vitae, *Thuja occidentalis* Linn., which grows in the cedar swamps of central and northern Wisconsin and furnishes the common cedar posts and rails. Old white cedar trees sometimes have brown or reddish heart wood and are then erroneously termed "red cedars" by lumbermen.

⁴ *Pyrus coronaria* Linn. and *P. ioensis* Bailey.

(3) The introduction of more susceptible varieties of cultivated apple especially the Wealthy. This may be the most serious phase of the problem as will be shown later.

(4) The possibility of increasing virulence of the parasite on the cultivated apple. This seems not impossible, but there is no experimental data bearing upon it.

Whatever the explanation, the fact seems clear that the rust has been much more aggressive as an orchard pest in recent years than formerly, and there is convincing evidence that, unless something is done to prevent, it will do even more harm in the future.

Complaints from Wisconsin orchardists of serious loss have come only within the last five years, but in certain cases the trees have been killed or rendered worthless in this time. Pammel (1905) who has had long acquaintance with orchard parasites in Wisconsin as well as of the similar conditions in Iowa wrote of Iowa conditions some ten years ago, "The outbreak of apple rust is certainly very unusual in this state. In my observations extending over a period of fourteen years, I have never seen the cultivated apple affected". In a recent letter he states that this statement applied likewise to his early observations in Wisconsin.⁵

In other sections of the country apple rust is tending to increase in seriousness as an orchard pest. For example, Giddings and Neal (1912) writing of conditions in West Virginia state that "the rust of the apple has been one of the most serious diseases found in many of the orchards of West Virginia during the past few years the damage this year in one county is placed at \$75,000 It has been spreading rapidly into new localities during the past three seasons". Reed, Cooley, and Crabill (1914) state that no other fungus disease has produced nearly so much injury to the apple crop of Virginia and estimate the immediate loss of one year at upwards of one-half million

⁵ We quote, by permission, from a recent personal letter from Dr. L. H. Pammel botanist of the Iowa State College, who formerly lived in Wisconsin, and is familiar, with its flora. "Apple rust has been on the increase in recent years in Iowa, especially on the Wealthy. This is also true for western Wisconsin. I can remember when there was none on the cultivated apple in Wisconsin and Iowa. On my father's farm at La Crosse there were several red cedar trees, but I never saw the rust on the cultivated apples. It is to be noted that in those days the Wealthy variety was grown only occasionally. I do not think there has been any noteworthy increase of the red cedar or wild apples in western Wisconsin, where these species have always been common. I have long thought that the increase of rust on the cultivated apple is due to (1) the introduction of susceptible varieties like the Wealthy, and (2) increased virulence of the fungus." The first point is also made in a publication by Pammel (1906).

dollars with still further damage from the impaired vitality of the trees.

Since this rust problem is likely to become more serious as commercial apple culture develops in certain sections of Wisconsin, orchardists should know the danger and the means of reducing it. This requires first an understanding of the details of the peculiar life history of the parasite. Figure 3 shows this and the following figures and descriptions give the details more exactly.

I. ON THE RED CEDAR

The fungus passes its winter stage on the red cedar. Spores coming from infected apple trees fall on the leaves of the cedar, germinate and produce rootlike threads which penetrate the tissues of the cedar⁶. This lives in the tissues of the cedar during the summer and winter following infection without producing any swelling or other external evidence of its presence, but the next spring, when the cedar is rapidly growing, the tissues are abnormally stimulated at the points of infection and develop into galls or "cedar apples" (Figure 4). The galls thus produced remain dormant during the following winter and do not become active in the spread of the disease until the second spring following infection. They are brownish in color, of firm texture, rather irregular in form—usually more or less spherical or kidney-shaped, and may vary in size from a sixteenth of an inch to an inch and a half or two inches in diameter. During the early part of the winter the surface of the new gall remains comparatively smooth, but in the latter part of the winter it becomes pitted as is shown in Figure 4. During the latter part of April or the first of May each pit gives rise to a long finger-like projection which consists primarily of a mass of two-celled spores⁷. These spores do not germinate at once but when the warm rains come in May the finger-like spore-masses swell, become soft and gelatinous (Figure 5) and assume a bright orange yellow color. It is while in this condition that

⁶ Such fungus threads are called the *mycelium* and it is in this mycelium stage in the cedar, not as free spores, that the parasite winters over.

⁷ These primary two-celled cedar rust spores, as shown in Figures 3 and 6, are called teliospores, the germ tube produced by the teliospore is called the promycelium and the smaller secondary spores borne on these are termed sporidia. It is these sporidia which may infect the apple.



FIG. 3.—THE LIFE HISTORY OF THE CEDAR GALL AND APPLE RUST

In May the cedar galls send out the gelatinous tongues, *c 1*, bearing millions of spores, *c 2*, which are carried by the wind to infect the half-grown apple leaves *a 1*. Within about a month the apple leaf shows yellow rust spots dotted on the upper side with black dots, *a 2*. Soon the rust spots thicken and develop spore cups on the lower surface, *a 3*, from which the spores *a 4*, are carried during late summer to the cedar twigs *c 3*. Minute galls, *c 4*, appear on these twigs the next spring following infection. During this second summer these enlarge, and after overwintering in this dormant state, *c 5*, are ready the third spring to produce the gelatinous tongues shown in *c 1*.

the spores germinate, producing short germ tubes on which in turn are borne smaller secondary spores (Figure 6 c, d). One can hardly conceive of the enormous reproductive powers of such a fungus. Lloyd and Ridgway (1911) calculate from their studies that we might have as many

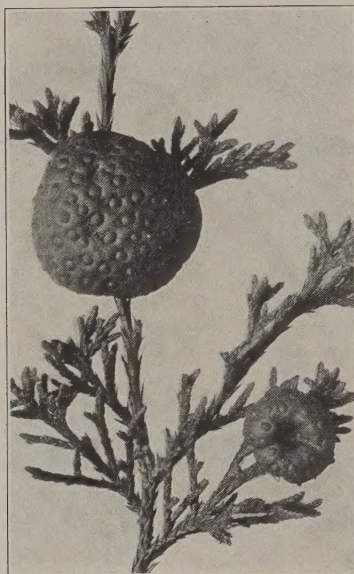


FIG. 4.—CEDAR APPLES

The rust fungus lives through the winter in these galls on the cedar twigs. In the spring a gelatinous spore-bearing tongue (see Figure 5), is developed from each of the circular spots on the gall.

as 7,440,000,000 spores developed from a single medium-sized gall, while Reed, Cooley, and Crabill (1914) calculate that these secondary spores from one average-sized cedar apple would, if placed end to end, form a continuous line a mile and a half long. It is these cedar-rust secondary spores which being carried by wind, insects, or otherwise, cause infection on the apple. The great abundance of these secondary spores and their minute size favor their transportation by the wind for long distances. As will appear later (Table I) we have found infection on the apple

abundant at one-fourth mile to one mile distant from the cedars which were the source of spore production. Giddings and Berg (1914) report serious defoliation in orchards three-quarters of a mile from the nearest cedar trees. Sea-



FIG. 5.—SPORE-BEARING CEDAR APPLE

During warm, rainy weather in May these bright orange tongues are very conspicuous. Myriads of spores are developed from each to infect the apple. (Fig. 6.) A single cedar gall like this may produce over seven billion such spores.

sonal conditions that are favorable for the development of the fungus on the cedar are also favorable for the development of the apple foliage, so that by the time the spores are ready for germination the young leaves and fruit of the apple are in the best condition for infection.

II. ON THE APPLE

The secondary spores from the cedar being transferred to a susceptible variety of the apple, germinate at once, under favorable conditions of moisture, and send their germ tubes into the tissues of the leaf, fruit or twig (Figure 6*d*). Infection can occur only on the young developing parts. It has been shown by Coons (1912) that the chief



FIG. 6.—SPORES DEVELOPED ON THE CEDAR APPLE

Progressive stages as seen under the microscope. *a*, Mature, two-celled primary spore. *b*, Germination of the same; a tubular outgrowth arising from each cell. *c*, The secondary spores developing from this outgrowth. *d*, Three of these secondary spores developing their germ tubes which infect the young apple leaves.

infection of the leaves occurs through the upper leaf surface. About ten days after infection takes place, light yellow spots begin to appear on the upper surface. As the fungus spreads within the leaf tissues the spots become larger and assume a bright orange-yellow color. A few weeks later a small group of black specks⁸ may be seen near the center of each such rust spot. In late June or in July the fungus further develops cushion-like swellings on the under surface of each yellow rust spot. Upon these swellings little pustules soon appear which grow into tubelike projections. These

⁸ These specks mark the openings of small flask-shaped vessels called the pycnia. Their function is not known but it is not probable that they play any essential part in the life history of the disease.

projections remain closed for a time but finally split down the sides, then the edges curl backward and expose a mass of brown spores⁹. (Figure 7). It is these apple rust spores which, being carried by the wind or otherwise to the cedar, produce infection, and thus we have the life circle of the fungus complete.

The rust attacks, under Wisconsin conditions, as previously noted, are almost always confined to the leaves and the damage is the result of leaf destruction. The rusted leaves



FIG. 7.—SPORE DEVELOPMENT ON THE APPLE

Diagrammatic drawing at the left of a single spore cup from Figure 2, magnified to show the spore content. At the right three of the spores from this cup, still more magnified. It is these spores which infect the cedar.

are in all cases weakened and in bad cases they begin to die and fall by mid-summer. Such early defoliation, of course, weakens the tree seriously and so saps its vitality that the fruit is of low value and where the rust occurs two or three successive seasons the tree may succumb and die (See Figure 15). Sometimes the fruit is attacked also (Figure 2), in which case it is ruined. While this fruit injury is serious in West Virginia and some other states, it has been less important under Wisconsin conditions. The young twigs also may be attacked, but this has not been observed to cause injury in Wisconsin on cultivated fruit although not uncommon on the wild crabs.

⁹ These tubelike projections which develop into spore-bearing cups are known as aecia and the spores produced within them are termed aeciospores. It is these apple rust spores, or aeciospores, shown in Figures 3 and 7, which may infect the cedar.

DISTRIBUTION OF THE RED CEDAR IN WISCONSIN ORCHARD SECTIONS

Since the rust occurs native on the red cedar and will pass from that to the cultivated apple when these grow in proximity, it is of much importance to the future apple



FIG. 8.—THE DISTRIBUTION OF THE RED CEDAR IN WISCONSIN

The red cedar is scattered throughout southern Wisconsin, especially on rocky hills and on bluffs bordering lakes or streams. It follows the Mississippi River throughout its course in Wisconsin, and reaches back from this some distance up the valleys of the larger tributary rivers, the Wisconsin, Eau Claire, and St. Croix.

industry of Wisconsin to learn the distribution of the native cedar. It is especially important to map this out in relation to the areas of the state suited to commercial orcharding. A canvass has, therefore, been made to determine where the cedar occurs. Figure 8 shows the points at which the

red cedar is known to exist; of course, it has been introduced by planting at various other places. The Horticultural department of this station prepared a similar map some



FIG. 9.—COMMERCIAL ORCHARD SECTIONS OF WISCONSIN

The areas known to be well adapted to commercial apple orchards are shown by heavy shading; while the light shaded areas are those giving promise of becoming important orchard districts. Not all the land within these areas is adapted to fruit-growing and many limited sections outside of these areas may grow good fruits on a commercial scale. (Map by Professor J. G. Moore.)

years ago showing the present and prospective orchard regions of the state as shown in Figure 9. By a comparison of these figures it can be seen that there is a general similarity between the two. No doubt the red cedar is to be found in many other localities than those shown on the

map, but sufficient evidence is here presented to show that there is a pretty general distribution of the cedar over the southern portion of the state and along the Mississippi River Valley as far north as Polk County. By referring to Figure 9 it will be seen that, with two important exceptions—the Door County and Bayfield peninsulas—this is the portion of the state in which the largest commercial orchards are found or are likely to be developed.

The significance of this is evident. In Sauk and La Crosse Counties complaints of rust injury to orchards are already heard. In Kickapoo Valley commercial orchard plantings are being made in regions where the cedar abounds. Unless preventive measures are taken, the rust injury is sure to increase, and to certain varieties of apple, like the Wealthy and Jonathan, may prove ruinous.

REMEDIAL MEASURES

The rust diseases are among the hardest to control. This is notably true of the apple rust since it involves consideration of the two host plants—the cedar and the apple. As will be explained there is no single specific remedy applicable to all cases. The ones which have received consideration as offering chief reliance are (1) spraying, (2) cutting the cedars, and (3) varietal resistance. These will be discussed in order.

I. SPRAYING

Spraying the apple.—It will be shown later that the chief reliance must be placed upon the other control measures, viz., elimination of the cedar, or proper location of the orchard, so as to avoid the cedars, and selection of hardy varieties of apple. There are certain cases, however, where commercial orchards containing susceptible varieties are so located that it seems impracticable to eliminate the red cedar. In such cases spraying seems to be the only hope. Attempts have, therefore, been made to control the rust by spraying the apple in early spring. Previous to 1911 spraying experiments for the control of apple rust had been

conducted by various men¹⁰ with negative results or only partial success. In that year, Giddings (1911) reported a case that came under his observation in West Virginia where very favorable results were secured by spraying. The next year Giddings and Neal (1912) published the results of experiments carried on under their own direction which encouraged them to say "These investigations have



FIG. 10.—CEDAR BLUFF

Along the base of this rocky wooded hillside in Sauk County, young orchards, including many Wealthy trees, have been planted. Red cedars abound all over this bluff and the rust is devastating the orchards.

definitely shown that apple rust may be controlled by the spray mixtures in common use, *provided the application is made at the right time*".

While Giddings was conducting his experiments in West Virginia, similar trials were under way in Wisconsin, of which a preliminary report has already been published (Bartholomew, 1912).¹¹

The orchards chosen in which to conduct our spraying experiments were all in the Baraboo River Valley near Baraboo in Sauk County, Wisconsin. The red cedar

¹⁰ Reference should be made in this connection to the results obtained in Vermont by Jones (1890, 1891, 1892), in Nebraska by Emerson (1905), Hein (1908), and Heald (1909) in Virginia by Reed and associates (1912).

¹¹ In this connection we wish to record our indebtedness to Messrs. L. H. and J. W. Palmer of Baraboo and Professor Frederick Cranfield, Secretary of the Wisconsin Horticultural Society, all of whom have advised and assisted in these investigations most cordially and helpfully.

abounds in the rocky woodlands covering the ridges of this vicinity and its entire elimination seems at present quite impracticable. During recent years increasing attention has been given to commercial orchard planting hereabouts and now, just as these orchards are coming into profitable bearing, the plague of rust threatens to ruin certain varieties. Experimental sprayings were made in three



FIG. 11.—PROTECTION BY SPRAYING

Looking into the tops of two Wealthy apple trees. The one at left unsprayed, defoliated by rust. The one at right sprayed three times, well protected. See also Figure 12.

orchards lying in the valley overlooking which is a steep wooded hillside where the red cedar abounds. (See Figure 10). The first of these, belonging to L. H. Palmer, is located about one mile from this cedar ridge; the second, Frank Kasten's, is immediately at the base of the ridge. These two orchards, lying nearest the source of infection contained trees that were either dead or dying because of being almost completely defoliated by the ravages of the rust during the two previous seasons. The Wealthy being most susceptible, trees of this variety were chosen upon which to conduct the spraying experiments.

Weather conditions, the development of the apple foliage and the maturing of the galls on the cedar were closely watched. Immediately following the formation on the cedar galls of the jelly-like spore-bearing fingers the apple trees were sprayed with Bordeaux and arsenate of lead mixture.¹² The aim was to apply the spray before sufficient time had elapsed for the spores from the cedar galls to be carried to the apple foliage. The first spraying was



FIG. 12.—RUST CAN BE PREVENTED BY SPRAYING

Wealthy apple branches from the experimental orchard, Baraboo. The branch at left unsprayed, badly rusted. The leaves at right show splashes of the Bordeaux spray, three applications of which kept them free from rust.

on May 15, with subsequent applications on May 22 and May 30. The proper time for spraying, however, cannot be designated by any fixed dates, for the crucial time for action depends entirely upon such weather conditions as favor the development and dissemination of the spores from the cedar galls. Collections of cedar galls were made at the time of each spraying. On May 15 comparatively few of the gelatinous fingers had developed on the galls while on May 22 perhaps half of the gall was covered, and not until the time of the third spraying (May 30)

¹² The Bordeaux mixture was of the standard type, 4 pounds lime, 4 pounds copper sulphate, 50 gallons of water, reducing to 3 pounds of each lime and sulphate in the later sprays. To each 50 gallons of this mixture 3 pounds of lead arsenate was added for the insects.

were the galls completely covered with the jelly masses. Thus the period of possible infection extended over an interval of some three weeks.

The gain from spraying was strikingly evident. During the latter part of the summer, after the rust had fully developed on the apple foliage, a limb was taken at random from each of the sprayed and unsprayed trees and the number of infected and uninfected leaves was determined, together with the minimum and maximum number of infection spots on the diseased ones. The results are shown in Table I.

TABLE I.—RUST ON TREES IN ORCHARDS NEAR CEDAR BLUFF¹

Tree	Leaves not In- fected	LEAVES INFECTED		RUST SPOTS PER LEAF	
		Number	Percentage	From	To
Kessler Orchard at base of Cedar Bluff					
Sprayed					
1	86	17	16.1	1	2
2	29	1	3.3	1	25
3	65	12	15.5	1	36
4	113	8	6.6	1	5
Unsprayed					
1	11	29	72.5	1	138
2	48	56	53.9	1	38
3	20	29	58.8	1	92
4	46	68	59.7	1	112
Kasten Orchard ¼ mile from Cedar Bluff					
Sprayed					
1	33	2	5.7	1	8
2	66	48	42.1	1	8
Unsprayed					
1	43	54	55.7	1	33
2	39	48	55.2	1	28
Palmer Orchard a mile from Cedar Bluff ¹					
Sprayed					
1	60	1	1.6	....	....
2	86	1	1.1	....	....
3	52	3	5.6	....	....
4	91	1	1.09	....	....
5	94	3	3.0	....	....
6	84	2	2.3	....	....
7	70	1	1.4	....	....
8	78	0	.0	....	....
9	80	0	.0	....	....
10	122	0	.0	....	....
11	102	1	.09	....	....
12	30	0	.0	....	....
Unsprayed					
1	52	3	5.6	....	....
2	87	6	6.4	....	....
3	89	7	7.3	....	....
4	144	10	6.5	....	....

¹ Each infected leaf showed an average of from only one to two infection spots in this orchard which was not as a rule a serious matter and was far less than in the two other orchards nearer the cedars.

On the lower half of the tree where the application of the spray was more thorough there were many branches practically free from the disease. This was not due to unlike exposure to the disease for no such contrast could be detected on the unsprayed trees.

Table I also shows very clearly that while the infection may spread to a greater distance it is much less serious when the cedars are half a mile or more from the orchard.

Our results agree with those reported from West Virginia by Giddings that the greatest attention must be given to the time of application. The developing apple leaf according to Fulton (1913) is most susceptible when about half developed. He found that each leaf passes from a condition of immunity¹³ when very young to one of maximum susceptibility at a little more than half size, thereafter becoming less susceptible with increasing age until it is again wholly immune. Giddings and Berg (1915) experimenting in West Virginia upon the York Imperial apple find that infection may take place as soon as leaves have unfolded enough to expose a portion of the upper surfaces. Since the apple twig is making rapid development during this infection period frequent sprayings are necessary in order to keep the newly developed leaves adequately protected. The spores are developed and scattered abundantly whenever during this period a rain, which swells the jelly-like fingers on the cedar galls, is followed by brief drying. Coons (1912) has, however, shown that the secondary spores may be forcibly discharged into the air so that it is not necessary for these gelatinous masses to become fully dry before spore dissemination occurs. He concludes that infection may take place, even during a rainy spell, if that lasts longer than from twelve to twenty-four hours. It is also to be noted, as recently emphasized by Crabill (1913), that under certain conditions the secondary spores continue to multiply. All of this shows that even with critical attention and repeated sprayings, adverse weather conditions may make satisfactory results from spraying quite impracticable.

All that can be said is that where one has trees of especially susceptible varieties like Wealthy and cannot eliminate the cedars he should aim to spray them two or three times during this susceptible period. The applications should be so timed as to protect the successive leaves as they begin to expand and especially so as to have them

¹³ Recent observations by Giddings and Berg (1915) have shown that a rain lasting at least two or three hours is usually required to bring about spore-production and discharge and that this spore-discharge continued for only a few hours after a rain.

coated with the fungicide immediately following each rainy spell. Reed, Cooley, and Crabill (1914) conclude after three years' experience in spraying that "if the young apple leaves can be coated with spray material soon after they unfold and kept coated until the first week of June, spraying will be effective in controlling this disease. It is especially important that the first spraying be made as soon as possible after the blossoms fall. In fact the first applications may be made when there are yet some blossoms on the tree." Bordeaux mixture seems preferable under Wisconsin conditions but Giddings and Berg (1915) have found in West Virginia lime-sulphur solution (1-40) gives a little better results than Bordeaux mixture, and Reed, Cooley, and Crabill (1914) favor a copper-lime-sulphur mixture made by adding copper sulphate to the ordinary lime-sulphur solution at the rate of 2 pounds in 50 gallons. In any case, the expense and uncertainty of spraying are such as to emphasize the importance of attention to the other control measures wherever practicable.

Spraying the cedar.—The infection of the cedar by the apple-rust spores occurs during a prolonged period from July to September. Careful and repeated sprayings would be required to prevent this infection. Obviously this would rarely be worth while even if successful. As a matter of fact, however, carefully conducted experiments by Heald (1909) in Nebraska showed that even with repeated applications complete prevention of the rust was not possible. His results are reproduced in Table II. He used a Bordeaux mixture consisting of 1 pound lime, 1 pound copper sulphate, and 12 gallons water to which was added half a pound of soap. The sprayings were made in 1907; the galls on the cedars were counted the next summer.

TABLE II.—RESULTS OF SPRAYING RED CEDARS

Group of trees	Dates of Spraying	Gallons per sprayed tree	Gallons per unsprayed tree
I	July 26; Aug. 6, 15.....	48	950
II	July 26; Aug. 6, 15, 29; Sept. 12, 26; Oct. 9.....	140	1500
III	Aug. 15, 29; Sept. 12, 26; Oct. 9.....	159	1400
IV	Sept. 2, 12, 26; Oct. 9.....	1400	1450 estimated

Although the number of galls was much reduced by spraying, this is of little consequence so far as concerns control of the apple rust, inasmuch as the number of galls remaining would be amply sufficient to reinfect the neighboring apple trees. Heald's conclusions may be accepted, therefore, that "the reduction of the number of galls is not sufficient to be of much value in preventing the infection of adjacent apple trees". He states, however, that where the life of the cedars is threatened by the rust, spraying may keep them from being thus killed. As a matter of fact the arguments are generally stronger for killing the cedars than for attempting to protect them.

II. REMOVAL OF THE RED CEDAR

The rust fungus cannot live over winter except in the tissues of the red cedar. It follows that the simplest remedial measure where this is practicable is to destroy all the red cedars in the vicinity of the orchard¹⁴. Where this can be done the rust disappears like magic as was shown by the senior author over twenty years ago (Jones, 1892).

In certain regions where the red cedar is not native, it has been planted as an ornamental tree and cases of this kind have been observed in the state where a single small red cedar was ruining many neighboring apple trees. Sometimes this mischief can be checked by carefully pruning off all the cedar apples before they swell and discharge spores in the spring, but few people will have time or patience for this. Fortunately, however, the cedar has as a rule so little value as an ornamental tree that there is little objection in ridding the neighborhood of such public nuisances by uprooting them.

The difficulty is more serious where the cedar is native. It occurs especially in rough pastures, rocky ridges, clinging to cliffs, along streams, and in other similar places that are difficult or expensive to clean up. Our observations, as already noted, and the experience of others have shown serious infection of orchards where the nearest cedars were a half mile or more away providing favorable wind currents

¹⁴ In West Virginia where this rust is highly injurious to apple orchards a recent state law empowers the Crop Pest Commission to enter private property and destroy red cedars wherever they are a menace to the apple-growing industry. Possibly something of this sort may prove necessary in order to control the situation in certain localities in Wisconsin.

prevail. Hence any campaign of cedar extermination must be thorough and the cedars burned promptly if cut in winter or spring (Figure 13). Orchards are being planted frequently in narrow valleys fringed by cedar-bearing hills or ridges where the extent of the cedar growth and the limitations of ownership make it quite impracticable



FIG. 13.—CEDAR BRUSH READY FOR THE FIRE

A pile of red cedars cut from fields adjacent to a young Crawford County orchard which is shown in the back ground. This was cut in April and the cedar galls began to produce spores after cutting. Moral: burn promptly.

to exterminate the cedar. In certain cases the value of the cedar may possibly outweigh that of the orchard.

In such cases it is important to recognize the limitations thus necessarily imposed on orchard development. Rust infection is sure to come and to increase year by year. One must, therefore, choose, if he is to have apples under such conditions, between the necessity of persistent spraying, with unsatisfactory results even then, or the elimination of certain susceptible varieties from his orchard.

III. VARIETAL SUSCEPTIBILITY AND RESISTANCE

One of the most striking things observable when the rust infection is severe in an orchard containing several varieties of apple is the marked variation in varietal susceptibility.



FIG. 14.—RUST RESISTANCE

Wealthy trees at right defoliated and dying because of rust. Wolf River trees at left immune. Orchard not sprayed.

Figure 14 illustrates how a susceptible variety may be killed while an adjacent tree of a resistant variety is quite unharmed. Similar differences have been recorded by others. The following is a list ¹⁵ of susceptible and resistant varieties as reported from several different states.

¹⁵ Based upon reports from Nebraska by Hein (1908); from Virginia by Reed, Cooley, and Crabill (1914); from West Virginia by Giddings and Berg (1915); from Iowa by Pammel (1905); and from Connecticut by Clinton and Britton (1911).

In addition Lloyd and Ridgway (1911) published a carefully prepared list for Alabama in which they include 36 varieties as resistant, 33 as slightly affected and 19 as badly affected. This list is not reproduced because of its length and the fact that these extreme southern lists have little practical significance for northern orchard practise. In Table III, however, we have checked from the Alabama list such varieties as are given in their table.

Virginia.—Resistant varieties.—Winesap, Arkansas (Mammoth Black Twig), Stayman's Winesap, Northwestern Greening, Grimes, and Yellow Newtown (Albemarle Pippin).

Susceptible varieties.—York Imperial, Northern Spy, Rome Beauty, Jonathan, and Ben Davis.

West Virginia.—Immune varieties.—Baldwin, Winesap, Arkansas Black, Stayman, and Yellow Transparent.

Resistant varieties.—Black Twig, Grimes Golden, and Maiden Blush.

Susceptible varieties.—York Imperial, Rome Beauty, Wealthy, and Jonathan.

Moderately susceptible.—Ben Davis and Northwestern Greening.

Nebraska.—Resistant varieties.—Duchess, Sweet June, Yellow Transparent, Ben Davis, Maiden Blush, Winesap, Grimes Golden and Red Astrachan.

Susceptible varieties.—Wealthy, Red June, Whitney, Jonathan, and Missouri Pippin.

Iowa.—Resistant varieties.—Hibernal, Duchess, Fameuse, Canada Baldwin.

Susceptible variety.—Wealthy.

Wisconsin.—Our observations upon varietal susceptibility have been made in Wisconsin so far as opportunity has offered with the following results.

Resistant varieties.—Wolf River, Northwestern Greening, Fameuse (Snow), Duchess, McMahon, and McIntosh.

Susceptible varieties.—Wealthy, Peerless Sweet, Jonathan, Whitney, Sweet Wine, Plumb Cider, Dudley, and Yellow Bellflower.

These data are combined in Table III. These observations have been too limited for broad conclusions with reference to most of these varieties, especially when one remembers that disease resistance is a relative character which may vary with change in environment. This is illustrated by the fact that the Ben Davis is listed as susceptible in Virginia and West Virginia and resistant in

Nebraska. Nevertheless they offer the best guide available for Wisconsin orchardists and show beyond doubt that the Wealthy is susceptible in the highest degree, the rust causing such complete defoliation in bad cases as to kill the trees of this variety within a few years. This is of the greatest practical importance, since the Wealthy is the most popular variety now being planted in Wisconsin. Any one planning its use in a commercial orchard in the red cedar zone should bear in mind this danger. *The Wealthy apple cannot be successfully grown in the same neighborhood with the red cedar.*

TABLE III.—RELATIVE RUST RESISTANCE OF APPLE VARIETIES

SUSCEPTIBLE VARIETIES	Va.	W. Va.	Neb.	Ala.	Ia.	Wis.
Ben Davis	+	+				
Brier Red	+					
Dudley	+					+
Jonathan	+	+	+	+		+
Missouri Pippin			+			
Peerless Sweet						+
Plumb Cider				+		+
Red June			+	+		
Rome Beauty	+	+		+		
Smoke House		+				
Sweet Vine						+
Wealthy		+			+	+
Whitney			+			+
Yellow Bellflower						+
York Imperial	+	+				
RESISTANT VARIETIES	Va.	W. Va.	Neb.	Ala.	Ia.	Wis.
Arkansas (Mammoth Black Twig)	+	+		—		
Arkansas Black		+				
Baldwin		*				
Ben Davis			+			
Canada Baldwin					+	
Fameuse (Snow)					+	+
Grimes' Golden	+	+	+	*		
Hibernal					+	
Maiden Blush		+	+	+		
McIntosh						+
McMahon						+
Northwestern Greening	+	*				+
Oldenburg (Duchess)			+		+	+
Red Astrachan		+	+	+		
Stayman Winesap	+	+				
Sweet June			+			
Winesap	+	+	+	+		
Wolf River						+
Yellow Newton (Albemarle Pippin)	+					
Yellow Transparent		+	+			

* Moderately susceptible.

As to the other varieties which may be considered standard for Wisconsin culture, the Dudley and the Plumb Cider are also to be avoided as susceptible where the red cedar occurs.

On the other hand, there are some of the best varieties, whether for home orchard or commercial culture, which are relatively resistant. Those who are planting orchards, in western or southwestern Wisconsin or elsewhere in the red cedar sections are advised to select as far as practicable Northwestern Greening, Fameuse (Snow), McIntosh, McMahon, Duchess, Red Astrachan, Yellow Transparent¹⁶, or Wolf River.

SUMMARY

Apple rust is on the increase in some sections of Wisconsin and threatens to become the limiting factor in commercial orcharding under certain conditions.

It attacks the leaves chiefly, causing a premature dropping of the leaves and may thus greatly weaken or soon kill the tree. It may also attack fruits and even twigs.

The same rust occurs on the native wild crab apples.

It is caused by a parasitic fungus which has a peculiar life cycle. It cannot spread from apple to apple and cannot live through the winter on the apple. Instead, the infection passes from the apple to the red cedar, (red juniper), winters on this, produces galls (cedar apples) and, from these, spores develop which reinfect the apple.

The disease can occur only where the red cedar and the apple—either the cultivated apple or wild crab—grow fairly close together.

As the red cedar is widely distributed in certain sections of the state where orchard planting is on the increase, the disease will be of far greater importance within a few years unless attention is given to precautionary or remedial measures. This applies especially to southwestern Wisconsin in the valleys tributary to the Wisconsin and Mississippi Rivers.

Two or three sprayings of the apple trees in May with Bordeaux, lime-sulphur, or lime-sulphur-copper mixture if so timed as to correspond with the spore discharge from the cedar galls will greatly reduce the amount of rust, but no practicable spraying will entirely prevent it. Spraying the cedar is ineffective. Reliance on spraying is, therefore,

¹⁶ The Yellow Transparent, while resistant to rust, is one of the most susceptible to fire blight. For this reason it is undesirable for most locations.

recommended only where resistant varieties and cutting the cedars cannot be resorted to. Hand picking of cedar apples may be practicable with an occasional ornamental tree.

The complete eradication of the red cedars for a radius of half a mile or more from the orchard is the sure remedy.

There is a marked difference in varietal susceptibility and those planting orchards in regions where the red cedar occurs should give careful heed to the fact that *the Wealthy is liable to be destroyed by rust if planted in the neighborhood of the red cedar.*

The following varieties, on the other hand, are relatively resistant to this rust: Northwestern Greening, Fameuse, McIntosh, McMahon, Duchess, Red Astrachan, Yellow Transparent, and Wolf River. Persons planting orchards in regions where the red cedar abounds should, therefore, use these or similarly resistant varieties.

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